3.0 PROCESS AND METHODOLOGY

3.1 Introduction

The preceding chapter defined cost estimating and discussed its categories, uses, and types. The next step is to understand the estimating process and to answer the question "How is the estimate accomplished?" The discussion in this chapter is drawn from a number of estimating references and represents a "common sense" approach to estimating distilled from processes used in a variety of organizations. The FAA, through the establishment of a central cost estimating function in the Investment Analysis Staff, has made significant progress toward improving estimating by fostering standardization of methods and processes. This will result in more consistent estimates and accuracy as the corporate history management system and estimate formulation techniques are refined. Therefore, the FAA cost estimator will want to refer to the guidelines for estimating developed by the Investment Analysis Staff, in addition to what is found in this chapter.

3.2 Cost Estimating Process

The cost estimating process can be viewed as a systematic approach consisting of the following steps or tasks:

- Plan the estimate (Chapter 4)
- Research, collect, and analyze data (Chapter 5)
- Develop estimate structure (Chapter 4, Section 4.5.1)
- Determine estimating methodologies (Chapter 3, Section 3.3)
- Compute the cost estimate (Chapter 6)
- Document and present the estimate to decision makers for use (Chapter 7)

As shown above, each task either is discussed in this chapter in its entirety, or introduced in this chapter and discussed more fully in later chapters of this handbook.

3.2.1 Planning the Estimate

The first step in developing an estimate is defining the estimating task and planning the work to be accomplished. The definition and planning stage includes determining the ultimate use of the estimate; understanding the level of detail required; outlining the total characterization of the system being estimated; establishing ground rules and assumptions; selecting the estimating methodologies; and finally, summarizing all of these in an estimating plan. Chapter 4 will provide a detailed examination of each of these areas. For now it is important to understand that task definition and planning is an integral part of any estimate. It represents the initial work effort and provides the framework for achieving a competent estimate efficiently.

3.2.2 Data Research, Collection, and Analysis

A function of task definition and planning is the initial identification of estimating methodologies. Once methodologies have been identified, preliminary research can commence to determine the availability of data required to support the final selection of the methodology. This research may dictate a different approach due to lack of adequate data. For instance, if an analogy method (Section 3.3.2) is initially selected, but technical and cost data are not available on a similar system, a parametric method (Section 3.3.1) may have to be employed instead. Beyond preliminary research, this estimating phase will involve one of two paths, or both, depending on the selected methodology.

On the first path, data research, collection, and analysis may be required to develop a cost estimating relationship (CER) to estimate a particular area. This path involves a considerable amount of time. In addition to the research, collection, and analysis of the data to be used, the cost estimator must construct the estimating relationship and ensure it is statistically sound and logically represents the area to be estimated. If the hypothesis proposed at the start proves false, the cost estimator has invested a significant amount of time without deriving a workable methodology. The potential for this type of eventuality should be factored into the estimating schedule.

The second and most commonly used path is the direct application of historical cost data to the estimate, either through use of similar programs or data on the same programs. This approach involves research to determine the most applicable data to use. For instance, when estimating a modification to a radar system, it may be appropriate to limit the data collection to radar modifications rather than including new radar systems. These decisions require estimator judgment based on knowledge obtained during the definition and planning phase. The key point is to narrow the research scope to achieve a viable database in the time available.

The analysis portion of this phase should ensure that the cost data collected are applicable to the estimate. It often is necessary to delete elements of data and adjust or normalize others to derive a database that will support the selected methodology. When analyzing contractor data, the cost estimator must understand the peculiarities of each contractor's accounting system, work breakdown structure (WBS), and labor rate content. When applying historical factors to estimate various cost elements (e.g., systems engineering and program management as a percent of recurring hardware), the estimator must consider differences between the work content represented by historical data and that of the current system. The analysis function cannot be overemphasized. For this reason, analysis of contractor data is discussed throughout the handbook, and Chapter 5 is dedicated to this important subject.

In addition to technical and cost data, the estimator requires programmatic information to phase the estimate properly, understand interrelationships with other systems, and ensure inclusion of all cost elements. Normally as the estimating task is being defined and planned, this programmatic information will be collected. The following is a list of FAA source documents from which programmatic information is available. Specific estimate requirements along with the stage and nature of the program will influence the exact data to be extracted from these documents.

- Mission Need Statement
- Requirements Document
- Investment Analysis Report
- Acquisition Program Baseline (performance, cost, schedule, benefits, risk)
- NAS Architecture and budget planning documents
- Acquisition Strategy Paper
- Integrated Program Plan

Because the availability and applicability of data are key to the selection of cost estimating methodologies, it is important to understand the area of data collection in detail. Chapter 5 discusses this topic.

3.2.3 Development of the Estimate Structure

When forming the estimate structure for purposes of data collection, as well as the actual estimating task, the first step is to break down the estimate into broad groups of cost. For a LCC estimate, acquisition and O&M would form the basic sections of the estimate. The next step would be a further breakdown of these broad categories into more discrete areas of cost. Chapter 2 included a discussion of subcategories within these broad categories. However, when forming the estimating structure for a specific acquisition, the logical tool to use is the work or cost element structure. The work element structure refers to a hierarchical structure of work elements that defines the full family tree of a work activity. (Rodney D. Stewart, *Cost Estimator's Reference Manual*, page 4.)

A standardized form of work element structure that is commonly used by government agencies is the WBS. The WBS is used to manage acquisition programs by defining the elements of work typically found in acquisition programs. The FAA Standard Work Breakdown Structure is intended for use across the FAA for developing life cycle cost estimates of solutions and is available on FAST. It represents the complete set of activities that may be accomplished to provide a solution that satisfies a FAA mission need. The WBS also will support management of solutions during the solution implementation and in-service management phases, and will aid in the comparison of life cycle cost estimates to actual costs that are collected through the FAA Accounting System.

3.2.4 Determining the Estimating Methodology

There are various cost estimating methodologies that a cost estimator can use throughout a program's life cycle. The choice of the proper methodology for a given estimating scenario is clearly an important determinant for producing a good estimate. It should be noted that more than one methodology could be used during the course of preparing a cost estimate. Section of this chapter introduces a variety of cost estimating methodologies and focuses on the key factors to consider in choosing an estimating methodology. The three main estimating methodologies (parametric, analogy, and engineering), with step-by-step instructions on how to use each one, are explored in detail.

3.2.5 Computing the Cost Estimate

The coming together of data analysis, the cost structure, and the selected methodologies signal the start of number crunching, or the pulling together of the estimate. Generally, an electronic spreadsheet will be employed for the majority of the estimator's computing needs. Chapter 6 discusses in detail the process of entering data and methodologies into the physical structure of the estimate (the work element structure); time phasing the estimate; and dealing with inflation.

3.2.6 Documenting and Presenting the Estimate

The job is not finished when the numbers are down on paper or contained in an electronic spreadsheet. Throughout the performance of the estimate, the cost estimator should be considering the final product and how and where it will be reviewed and presented. The different types of estimates discussed in Chapter 2 require various levels of review and standards of presentation. Establishing a "baseline presentation package" during the early stages of the estimate is extremely beneficial because it provides a format that can be expanded to facilitate internal progress reviews. Since pertinent programmatic, cost, schedule, and technical information are captured, they will serve as the basis for the final briefing package. The FAA Investment Analysis Process guidelines include presentation and documentation formats that are required in the Investment Analysis Report. The estimator should refer to these guidelines for the most up-to-date information on formatting.

Establishing the baseline presentation package is another way of ensuring that all cost elements are being covered in the estimate, thereby eliminating last minute briefing preparations. Initial review of the baseline package with management will minimize the potential for surprises as the briefing enters the review cycle. Here again, the Investment Analysis Staff guidelines and the staff itself are an invaluable resource for the estimator.

Documentation is often viewed as the final task and, with that perspective, becomes a most difficult task. If documentation is left untouched until the end of the estimate, it becomes extremely difficult to recapture the rationale and judgments that formed the estimate. Four key considerations will be offered here regarding documentation.

- First, documentation should not be postponed until the estimate is complete. Documenting the estimate as it is performed lends efficiency to its preparation and quality to its content. The documentation process, if done diligently, will virtually eliminate calculation errors inherent to number crunching.

- Second, an abundance of detail is preferred to a shortage of information about an estimate. Documentation should start with the premise that the reader knows nothing about the program or estimate. Consequently, documentation should be written in a step-by-step fashion.

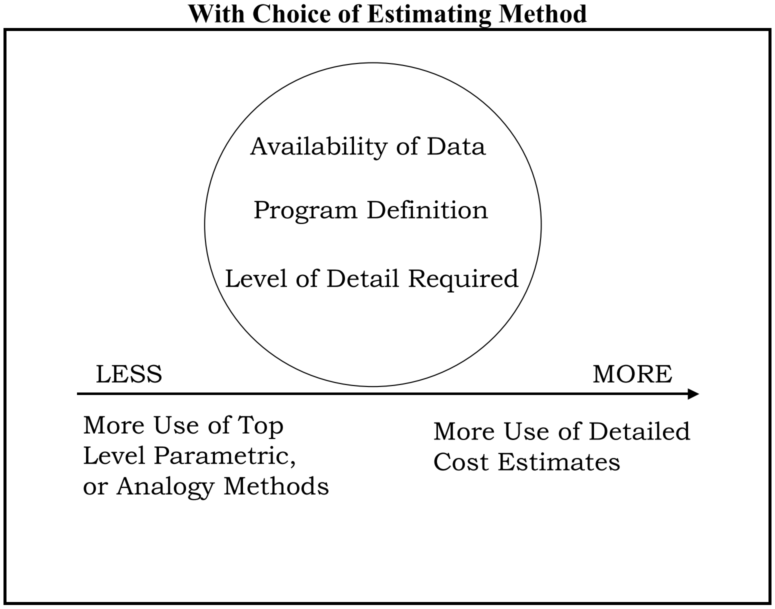
- Third, replication is the keystone of good documentation. Everything that is necessary to replicate the estimate by another cost estimator who had not participated in its formation should be included. Keep in mind that the person normally using the documentation is another cost estimator who needs to update the estimate contained in the documentation or desires to use it to support some other estimating endeavor. Consequently, it should represent a technical document and serve as a useful tool to the cost estimator referencing its content.

- Fourth, and finally, the written documentation package is frequently the only exposure that reviewers and users have to a cost estimate. Consequently, for many reviewers, it may become the sole basis for judging the quality of the estimate. Others view a poorly documented estimate as a poorly conducted estimate; hence, little credibility will be placed in the results of that estimate. In addition, the cost estimator is likely to be regarded as incompetent and may lose one of the most valuable attributes required of all cost estimators, credibility.

3.3 Estimating Methodologies

When choosing a methodology, the cost estimator must always remember that cost estimating is a forecast of future costs based on a logical extrapolation of available historical data. Therefore, availability of data will be a major factor in the estimator's choice of estimating methodology. In addition to availability of data, the type of cost estimating method an estimator chooses will depend on such factors as adequacy of program definition, level of detail required, and time constraints. These factors are all interrelated, as shown in Figure 3.1.

Figure 3.1 Interrelationship of Program Factors With Choice of Estimating Method



Availability of data clearly affects the choice of estimating methodology. The FAA AMS emphasizes the use of commercial off-the-shelf (COTS) and non-developmental Items (NDI), so the FAA estimator can anticipate frequent instances where there are actual or catalog prices for the item being estimated or at least closely analogous items to use as a basis for the estimates. This type of estimating is low risk and relatively simple to do. When little data exists, the cost estimator's choices are more limited and involve more cost estimating risk. For instance, if the estimator must estimate the cost of a completely new concept that exists only in the minds of scientists and has never been made before, data on such a system will be severely limited. There will be no actual production data and an analogy or actual costs from a similar system cannot be used. In this case, an expert opinion may be the only choice of estimating methodology. These are the two extreme examples in the spectrum of potential estimating scenarios.

Now consider the question of program definition and level of detail required - two factors closely related to availability of data. During the early stages of program planning in a developmental program, program definition is typically very broad and decision makers are considering several widely diverging solutions to meet their requirements. In this scenario, the use of a parametric model is a sound approach because parametric models can function with very little information. Once a design is baselined and the program is defined more adequately, an analogy approach might be feasible. A parametric model still can be useful when the design is baselined, but if a good analogous system is available, it becomes feasible to use this as the primary estimating methodology. When a prototype or initial production units exist, a detailed engineering methodology becomes a viable approach. With the FAA AMS emphasis on use of COTS and NDI items, the estimating challenge will be less rigorous than it would be if the FAA philosophy were to develop new systems. However, there will still be plenty of estimating challenges, such as estimating COTS and NDI integration costs and the costs of ensuring safety-critical performance.

Time constraints also affect the choice of estimating methodology. When the time available to do the estimate is limited, the time available to collect and process data is also limited. Under severe time constraints, the cost estimator may choose a top-level parametric model for the sake of expediency, if a good one is available.

The three major estimating methods are discussed in more detail in the next sections.

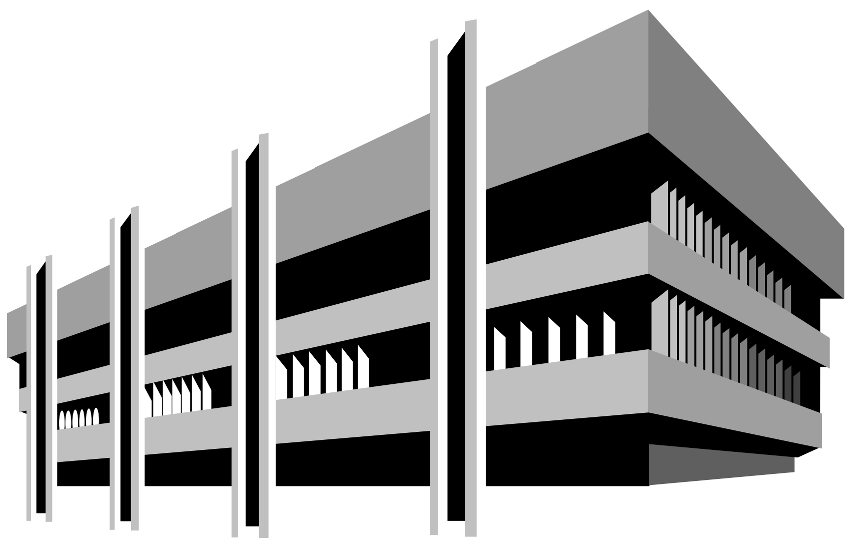
3.3.1 Parametric Estimating

The parametric method estimates costs based upon various characteristics or attributes of the system being estimated. It depends upon the existence of a causal relationship between system costs and these parameters. Such relationships, known as CERs, typically are estimated from historical data using statistical techniques. If such a relationship can be established, the CER will capture the relationship in mathematical terms relating cost as the dependent variable to one or more independent variables. Examples would be estimating costs as a function of such parameters as equipment weight, vehicle payload or maximum speed, number of units to be produced, or number of lines of software code to be written.

Parametric methods can be used to estimate costs at all levels of detail. As shown in Figure 3.2, they can be used to capture total costs of a system at a high level of detail such as when floor space is used to estimate building cost. On the other hand, they can also be used at a lower level of detail, for example to estimate the cost of electronic items. According to the *Joint*

Government/Industry Initiative Parametric Cost Estimating Handbook, certain manufacturers of electronic items have found that the cost of an electronic item varies directly with the number of electronic parts in the item. In other words, the sum of the number of resistors, capacitors, inductors, and transistors in a circuit design may be useful as a predictor of the circuit design's cost. This type of CER may be useful to an FAA estimator. There are also parametric cost models available to estimate the costs of individual custom microcircuit chips and/or electronic modules. Some of these models are flexible enough to allow input on custom chips, as well as COTS items. These models allow estimating at a very low level or a higher level of the WBS, depending on the availability of data.

Figure 3.2 Example of A Top Level Parametric Estimate



Building Cost = f{Floor Space}

This method is applicable to all elements of life cycle costs; but in the early stages of a program life cycle, this may be the only viable method because of limited program definition and data availability.

A widely used specific CER is the cost improvement curve, sometime called the learning curve. The theory states that as the total number of units produced doubles, the cost per unit declines by some constant percentage. In this CER, cumulative quantity is the independent variable; cost (measured by hours or dollars) is the dependent variable. Since quantity is the independent variable, this method works best when there is repetitive quantity production of like items. Table 3.1 shows an example of a 90 percent cost improvement curve. As the quantity doubles, the hours per unit to produce decreases by a constant 10 percent. If a company experiences a 90 percent learning curve, an estimator can use this information to predict what the cost per unit to produce is each time the quantity doubles. For instance, in Table 3.1, assume that an estimator has established that a 90 percent cost improvement curve has been observed in a manufacturing operation by reviewing the actual cost to produce certain quantities. With this knowledge, what would an estimator predict to be the cost required to produce a quantity of 16? Learning curve theory tells us that the cost to produce a unit should decrease by the amount of observed learning each time production quantity doubles. Production quantity has doubled from 8 to 16 units. Therefore, with a 90 percent learning curve, the cost to produce unit 16 should be 90 percent of the cost to produce unit 8. This equates to \$131 (\$146 for unit 8 × .90) to produce unit 16.

Chapter 9 discusses cost improvement curve applications and CERs in greater detail.

Table 3.1 90 Percent Cost Improvement Curve

Cumulative Units	Cost	Cost Reduction
1	200	--
2	180	10 percent
4	162	10 percent
8	146	10 percent
16	?	10 percent

The major advantage to using parametric techniques is that they capture major portions of an estimate in a limited amount of time and with limited program definition. Additionally, when using some of the more complex parametric models, the cost estimator is able to encompass the majority of the total program costs with this one method. Because CERs are based on actual program cost history, they reflect the impact of system growth, schedule changes, and engineering changes.

ADVANTAGE OF PARAMETRIC METHOD: This method can capture major portions of an estimate in a limited amount of time and with limited program definition.

There are, however, limitations to this methodology that an estimator should recognize. When the parametric employed captures cost at a very high level, it will not provide a low-level of visibility into discrete areas.

DISADVANTAGE OF PARAMETRIC METHOD: May not provide low-level visibility, and subtle changes in sub-elements cannot be reflected in the estimate easily.

As a result, subtle changes in areas such as design or manufacturing techniques cannot be reflected in the estimate. Another limitation is that individual pieces of the estimate may not be separable.

3.3.2 Analogy

The analogous or comparative method takes into consideration that no new program, no matter how advanced, represents a totally new system. Most new programs originated or evolved from already existing programs or simply represent a new combination of existing components. This method of estimating uses this idea as a foundation for estimating new components, subsystems, or total systems. Simply stated, it uses actual costs of a similar existing or past program, and adjusts for complexity, technical, or physical differences to derive the new system estimate.

Normally an estimator would choose this method when there is insufficient actual cost data to use as a basis for a detailed approach but an analogous item exists on which to base an estimate, e.g., a custom item is being built in a microcircuit. If the chip is very similar to one that has been made before, and the custom chip's difference can be quantified in terms of amount of new design or additional number of transistors, it may be possible to estimate from this information. Comparisons may be made in terms of functional capabilities, module size, material composition, number of sides used for component mounting, or design complexity. A detailed engineering assessment is required to ensure the best analogy has been selected and proper adjustments are made. The ability to break the estimate down into a low-level of detail further enhances the credibility of the estimate, since separate analogies can be chosen for each component.

ADVANTAGE OF ANALOGY METHOD: If a good analogy can be found, it allows for a lower level of detail, thus enhancing credibility.

DISADVANTAGE OF ANALOGY METHOD:
Can be difficult to find a good analogy and the required engineering judgment.

There are two limitations in using an analogous approach. First, is the requirement for a detailed program and technical definition of both the analogous system as well as the system being estimated. Engineering judgment becomes the mainstay of this approach and, at the same time, a limitation.

Without access to sound engineering support, this methodology is difficult to employ. Secondly, once the technical assessment has identified the analogous system, actual cost data on that system must be acquired. Without this, the transition from the analogous system to the current system cannot be made.

3.3.3 Engineering Estimating

The engineering method (also referred to as detailed, grassroots, or bottoms-up estimating) is an estimate that starts at a very low level of detail and builds up to a total cost. This type of estimate is used when detailed data are available on a system. Therefore, it is typical to find this type of estimate during Solution Implementation. At this stage of the life cycle, system technology and configuration are now expressed in actual cost data, and considerable detailed information is available about components and piece parts. The anatomy of such an estimate is shown in Table 3.2.

ADVANTAGE OF DETAILED ENGINEERING ESTIMATING: Level of detail makes it easier to substantiate a cost estimate.

Table 3.2 Anatomy of a Detailed Estimate

Skill	Man-hours	Labor Rates	Labor $	Overhead Rates	Overhead $	Labor Plus Overhead $	Gen. & Admin.	FEE	Price
Engineering									
Manufacturing									
Quality Assurance									
Tooling									
Test									
Material									
Total									

This figure shows how the detailed estimate proceeds from a basic skill breakdown. Man-hour estimates of each basic skill are made in some manner (through labor standards, a learning curve, or an analogy). The application of labor rates to these estimates of hours yields a labor dollar estimate. Material quantities and rates are estimated similarly and combined to develop a direct material dollar estimate. After that, overheads, general and administrative costs, and fee are applied to generate the total estimate. The detailed engineering estimate, as you can see from this discussion, can incorporate other methods such as analogy or parametric methods. What distinguishes the detailed engineering method of estimating from these other estimates is the level of detail.

The detailed engineering estimate requires large amounts of information concerning labor and material requirements, but also provides very detailed estimates on every aspect of the project. Electronic spreadsheets are invaluable in generating a detailed estimate because they allow easy adding and subtracting of the various elements and levels of the estimate. They also allow large amounts of data to be summarized into useful reports for management. When buying COTS items the vendor would usually have detailed cost estimates, but these are not presented to the government. The government may just see a price.

DISADVANTAGE OF DETAILED ENGINEERING ESTIMATING:
The time-consuming nature of the task and the need for detailed actual cost data.

3.3.4 Other Methods Often Used with COTS and NDI Procurements

The various other methods used are described below. The first two are excellent choices for COTS and NDI procurements.

- The vendor bid method is a good method where vendor price data exist, such as with COTS and NDI items. If the item is developmental, the usefulness of this method as an estimating tool is limited because cost estimates usually are required prior to receipt of bids. However, previously developed contractor estimates may be used at times, provided they are assessed as reasonable.

- A method used for estimating off-the-shelf items is catalog or handbook estimating. Handbooks, catalogs, and other reference books are published that contain lists of off-the-shelf or standard items with price lists or labor estimates. The estimator can use these catalog prices directly as unit values for standard components within a larger system.

- Expert estimating or specialist estimating is a judgmental estimate performed by an expert in the area to be estimated. Obtaining an estimate of lines of code from a software engineer or the number and duration of tests from the program test manager are examples of the use of this type of estimating approach. Surveying a number of experts independently to reach a consensus of opinion, the Delphi Technique also may be used. This methodology is limited by the availability of expert judgment and the credibility of that judgment. This approach is best used as a cross check against an existing estimate or in combination with other methodologies.

- The manloading method of estimating is an estimate made by a contractor functional manager or the estimator. The manager or estimator projects the number and type of skilled individuals needed to complete a specific work effort. The projection is then transferred into a man-hour estimate. This approach requires a high experience level. It is often used in combination with other methods. For example, the cost of contractor flight test support may be estimated by determining the number of individuals required at the test site.

- Industrial Engineering Standards (IES) - sometimes known as engineered standards - are used frequently as an estimating tool. Normally IES are used to estimate the time required to perform well-defined tasks in the manufacturing environment. A standard hours estimate is developed by summing the standard hours for each operation required to build the product. A standard hours estimate represents the optimum time required to produce the product and usually is unachievable in the real world. A realization factor is applied to the IES estimate to account for the reality of learning, lot sizes, and process inefficiencies.

- Estimates-at-Completion (EACs) can be obtained from the performance measurement data submitted on a Cost Performance Report or a Cost/Schedule Status Report. The trends indicated in the reports, by both cost variance and schedule variance, are indicative of past and present performance. These trends can be extrapolated carefully to predict the trend of the future. This extrapolation, added to the actual expenditures to date, supplies the estimator with an EAC. This is a useful method for estimating on-going programs that require such reports from contractors.

3.3.5 Combination Methods

Most estimates require the use of a variety of methods. A different approach may be used for each area of the estimate so that the total system methodology represents a combination of methodologies. The examples on this page help illustrate this concept.

The estimator chooses and combines estimating methodologies based on the peculiarities of the estimating task. As no two estimates are alike, there are many combinations of methodologies possible. The choice should be made after careful consideration of those factors listed in the opening paragraph of this section - adequacy of program definition, level of detail required, availability of data, and time constraints.

EXAMPLE: ENGINEERING APPROACH
For a system in production, the engineering approach is selected. To project future costs for each of the functional areas, cost improvement curves are employed. Catalog prices are used for off-the-shelf items.

EXAMPLE: PARAMETRIC AND ANALOGOUS APPROACH
An electronic module consists of off-the-shelf and custom components. For the off-the-shelf components, catalog prices exist. For the custom components, a parametric estimate based on number of pins, transistors, and gates exists. The components must be integrated to construct the module, which must then be mounted into a radar. The estimator uses expert engineering judgment to estimate the initial number of hours to integrate the custom and off-the-shelf chips and then applies a standard electronics industry learning curve to estimate the costs for all the electronic modules in the acquisition. Finally, radar insertion costs are estimated using insertion costs experienced on a similar program.

3.4 Summary

This chapter answered the question, “How is the estimate accomplished?” A successful estimate is the result of following a systematic estimating process. This includes planning, data research/collection/analysis, and selecting applicable methodologies, structuring the estimate, number crunching, and presentation/documentation of the estimate.

The main estimating methodologies fall into three general categories - detailed engineering estimate, analogy, and parametric. Most estimates will make use of a combination of methods. The estimator’s task is to choose the best methodology for the task, given estimating constraints.